International Journal of Agricultural Technology 2021 Vol. 17(1):13-32
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Rubber agroforestry system (RAS) practices to overcome rubber price and soil erosion in Southern Thailand

Chhiev, B. and Jongrungrot, V.*

Agricultural Innovation and Management Division, Faculty of Natural Resources, Prince of Songkla University, Hat Yai Campus, Thailand 90110.

Chhiev, B. and Jongrungrot, V. (2021). Rubber agroforestry system (RAS) practices to overcome rubber price and soil erosion in Southern Thailand. International Journal of Agricultural Technology 17(1):13-32.

Abstract Most of rubber agroforestry system (RAS) showed strategies to reduce the chemical methods. The economic margins of the 5 plots for 6-year simulation (2019-2024) were divided into 3 levels; high, medium, and low level of ability to overcome the low rubber price. Plot 1, 2 and 4 were high levels because stingless bee and bamboo in plot 1, sala in plot 2, and champadak and phakleang in plot 4 which provided more products, and the price of products were high. Especially, all these 3 plots had not spent much cost in the plots. Plot 5 was a medium level, plot 3 was low level. However, eaglewood trees in plot 3 provided very high income when age was proper for harvesting but beyond the 7-year simulation. Coffee trees in plot 5 would increase the products every year. All RAS plot practices are still an alternative to improve the livelihood of RAS farmer households. On the other hand, the plant community structure is composed of rubber trees with upper canopies and intercrops with lower canopies. When the rain come, all canopies are intercepted by absorbing the raindrops until saturated. So, the rest of raindrops would be stemflow and throughfall to the lower canopies and ground which covered by leaves and branches of rubbers and other intercrops that were fallen and decayed. These layers helped to prevent soil erosion caused by rainfall. The crown covers of all plants' canopies in representative areas of all 5 RAS plots ranged from 93 to 98% of area that provided a great potential to protect soil from direct rainfalls in raining season and had ability to keep moisture in the plots due to the multiple levels of vertical stratification and crown covers.

Keywords: Rubber agroforestry system, Economic margin, Plant community structures and crown covers, Southern Thailand

Introduction

Natural rubber has been cultivated in Thailand since 1900s. Thailand, over 90% of total rubber product is shared for exports and contribution about one-third in global market. The total rubber latex, 70% was contributed by Southern Thailand (Win, 2017). The top six rubber producers and exporters in the world are Thailand, Indonesia, Malaysia, India, Vietnam, and China which contributes 86.5% to global total output in 2016 (Markets Insider, 2017). Many factors influence rubber price, especially rubber demand and supply, fuel price,

* **Corresponding Author**: Jongrungrot, V.; **Email:** vichot.j@psu.ac.th

and speculators. Dynamic of these factors fluctuate rubber price. Since 2002, rubber price had increased continuously. Also, an intervention of government had supported in rubber industry during 2004-2006 and encouraged farmers to grow rubber trees nationwide. Some farmers have converted traditional rice fields into rubber areas which have expanded rubber product and contributed to oversupply in global market (Praktikantin, 2017; Research and Markets, 2016).

Current low rubber price poses important challenges to rubber producers. Also, low rubber price influences the production of both small-scale and large-scale rubber producers. low rubber price leads to reduce farm maintenance, increase tapping frequency and lack of respect for quality norms. Rubber producers' income has locked into their rubber plantations, so small-scale producers are pushed further into poverty, and it is an impact on wages of tappers at large-scale estates (Fair Rubber Association, 2016). Moreover, abandonment of traditional land-use practices in favor of single cropping system may have severe implications for food and nutritional security of rural population. Rural food security is predicted to become more tenuous in Mekong region. This also includes availability of natural resources providing products and biodiversity which rubber plantations do not provide (Häuser, 2015). Rubber is increasingly planted as marginal environments where risk of unsustainability is. Given this trend is urgent for monitoring systematic and regionwide, and quantifying plant losses and impacts on ecosystem service to underpin appropriate policy of interventions that limit environmental as well as societal impacts. The clearing high-biodiversity value land for a single cropping system is poorly adapted to local conditions and altering landscape function whilst not producing long-term sustainable yields, which ultimately compromises livelihoods (Ahrends *et al*., 2015). The conditions of rubber cultivation in steep slopes areas have significant impacts on hydrology, water quality and soil erosion (Wangpimool *et al*., 2016). Expanding rubber mono-system affects affects socio-economic conditions and livelihood of farmers and exposes them to economic and ecological hazards (Häuser, 2015).

Somboonsuke *et al*. (2011) showed that farmers have practiced RAS to get good solution for uncertainties of economics, and avoid traditional land-use practices in rubber mono-cultivation (Häuser, 2015). Furthermore, RAS has improved several good environmental conditions on farms such as more biological diversity, more containable organic matter, high humidity, much shady, less soil erosion, fewer weeds in farms, balanced ecosystem, and preventing damage caused by storms (Jongrungrot *et al*., 2014). In this study, RAS is considered an alternative to improve environment, and provided a great source of income to farmers. The study aimed to investigate the techniques of RAS plot management, perform economic margin and soil erosion control of RAS plots in Songkhla and Phatthalung provinces of Southern Thailand.

Materials and methods

Data collection

This study was conducted in Songkhla and Phatthalung provinces of Southern Thailand in 2018. Purposive sampling was used for selecting RAS plots. Five RAS plots of five farmers in four RAS categories were chosen as study samples. The data collection was divided into two types. Secondary data was collected from research reports, academic articles, online data. Primary data was collected in the field on real farms following two approaches of using questionnaire to interview RAS farmers and techniques of measuring and drawing plant profile and crown cover (Table 1), and to visualize plant community structures and crown cover of the RAS plots.

Table 1. The technique of measuring and drawing plant profile and crown cover

Stage No. Activities	Materials/instrument
Stage 1. Observation of the plot sample	Rubber agroforestry plots
Stage 2. Identifying a rectangular area (5×30 m) as a representative RAS plot	Tape measure, cables, poles, and hammer
Stage 3. Determination of plant's number	Stickers
Stage 4. Collecting data of plants in the rectangular area (Canopy radius, girth at breast height: G.B.H., and Height)	Tape measure and forestry pro Laser range finder (height meter)
Stage 5. Drawing the plant community structure and crown cover in the rectangle area	Pencil, ruler, eraser, and paper (A2)

Source: Kaewwongsri, P. (2019, March 12). Personal interview.

The primary economic data in each plot was collected in 2018. The converting products and inputs in the farms from 2019 to 2024 were forecasted which based on farmers' experiences and planning as well as academic data such as the number of dried rubber products by age of rubber trees (Table 2). Moreover, related prices of all products and inputs on farm from 2019 to 2024 were fixed by price in 2018.

Table 2. Amount of dried rubber products

Age of rubber trees (year)	Amount of dried rubber products (Kg/hectare/year)	Amount (%)
7-9	1,531	64
10-12	2,375	100
13-15	1,900	80
16-18	1,575	66
Over 19	1,350	57

Source: Calculation based on Gunalasiri *et al*. (2007)

Data analysis

Some academic tools were used to analyze the research data to correspond with each objective of the study. The content analysis was used to investigate different techniques that farmers applied in RAS plot management. The descriptive statistic was used to explore an effect of plant community structure and crown cover of RAS plots on soil erosion. The crown cover density percentage was calculated after drawing plant community structure and crown cover in representative area of each RAS plot by formula as follows:

$$\text{percentage of crown cover density} = \frac{\text{crown cover in representative area} \times 100}{\text{Representative area}}$$

The level of all plant canopies and crown cover of the canopies in the RAS plots are related to reduction of soil erosion in the area. If the crown cover density is not less than 70%, it means that the soil erosion in area is insubstantial (Ruangpanit, 2014). Kaewwongsri (2008) asserted that loss of soil in cultivated land is inversely proportional to crown cover of canopies. Olympe software was used to simulate the economic margins of different RAS plots for 7-year period (2018 to 2024).

Results

Plot 1 Rubber-based stingless bee (Trigona.) raising, ironwood (Hopea odorata Roxb.) and bamboo (Bambusa sp.)

The techniques of plot management

Topography condition of this plot is plain area, and soil is silt loam type. Firstly, rubber trees were planted on 10-rai area in 1999 by 7×3 m planting distance equalling to single row, 7 m inter-row and 3 m inter-tree in the same row. The rubber density is 76 trees per rai. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 3d/4 183/273 nil stimulation is used for the plot harvesting. Secondly, Ironwood trees also were planted in the middle of rubber inter-rows in 2014 by 7×3.5 m planting distance. So, the ironwood density is 65 trees per rai. Their branches have been pruned once a year. Ironwood and rubber trees will be harvested timber at the same time in 2039. Thirdly, bamboo plants also were planted in the middle of rubber inter-rows in 2015 by 14×12 m planting distance. So, the bamboo density are 9 bushes per rai. The farmers always prune bamboo branches once a week after harvesting bamboo shoots. Fourthly, stingless bee raising were started in 2007 on the same land management. In 2018, there were 50 beehives on this 10-rai area. Farmers arrange vitality of beehives and bees every rubber tapping day. The bees do not only find food from all plants in this plantation but also from other plants around there. Honey is always harvested 3 times from March to May every year. This RAS plantation had been applied organic fertilizer about 170 kg per rai per year in June and weeding has been practiced three times per year after weed growing well. Farmer asserted that this RAS plantation did not need chemical fertilizer because the fallen leaves of rubbers and intercrops decomposed into organic fertilizer. RAS practice is better than rubber monoculture because RAS helps to keep moisture in plot especially in dry season that the fallen rubber leaves fall. In 2018, stem girth of the rubber trees at 1.70 m height from the ground surface was 79.7 cm on average and the girth of the ironwood trees at 1.30 m height was 25.9 cm on average.

The economic margin

There are many products from this plot. In 2018, this plot was expended the total cost per rai equaled to 2,433 baht. The rubber product was 332 kg; the bamboo product (shoots) was 972 kg; and the stingless bee product (honey) was 9 liters per 5 beehives per rai that provided income 14,190 baht per rai, 14,580 baht per rai, and 9,000 baht per 5 beehive boxes per rai, respectively. Meanwhile, ironwood trees and rubber trees will be cut down to provide income in 2039. Therefore, in 2018, the farmer got the total margin from this plot equaled to 35,337 baht per rai. Simulation of economic margin per rai for 6-year period from 2019 to 2024 with the related prices fixed in 2018 (Figure 1) shows that the farmer will get low and constant rubber margin every year because of low and stable products by old rubber trees. Meanwhile, bamboo margin will increase every year owing to continuous increase of bamboo shoots by age. And annual stingless bee honey margin will rise outstandingly because the farmer will add the beehives every year and high price of honey. In 2024, the final year of the simulation, rubber product will share the margin about 11,847 baht per rai, bamboo product will share the margin about 19,410 baht per rai, and honey product will share the margin about 53,700 baht per rai. The total margin from this plot in 2024 equaled to 58,107 baht per rai higher than one in 2018 about 39.19%. Therefore, the farmer of plot 1 can overcome economic fluctuation even though rubber product and rubber price could still be low. Moreover, the plot still has the ironwood and rubber trees whose economic values will be accumulated by age. Stingless bees help pollinate various flowers in the plot and nearby, and all trees can give greatly environmental services.

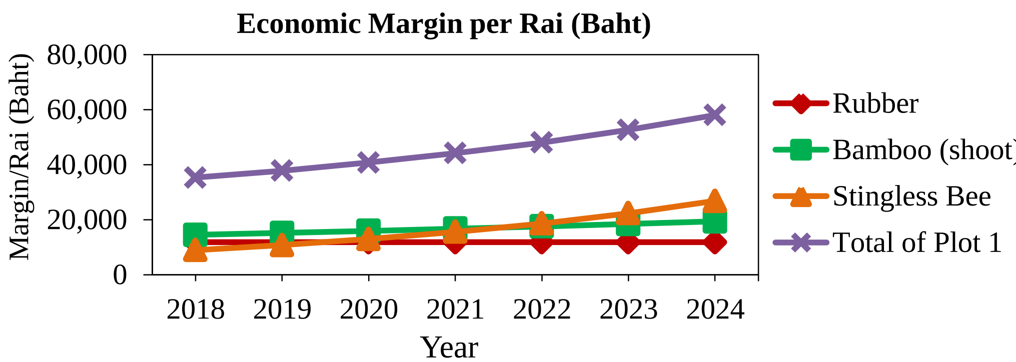
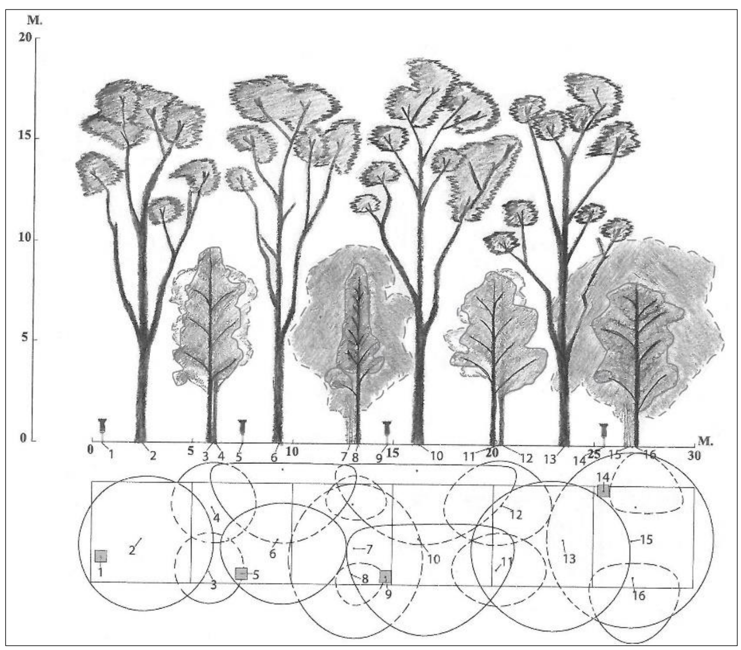


Figure 1. The economic margin of plot 1 from 2018 to 2024



Rubber trees	2, 6, 10, 13
Ironwood trees	3, 5, 8, 11, 12
Bamboos	7, 15
Stingless beehives	1, 5, 9, 14

Figure 2. The plant community structure and crown cover in the representative rectangular area (5×30 m) of plot 1

The plant community structure and crown cover

The vertical plant community structure and crown cover in representative 5×30 m rectangle area of plot 1 was illustrated in Figure 2. The plant community structure was composed of rubber trees with upper canopies as well as Ironwood and bamboos with lower canopies. The rubber trees, ironwoods and bamboos had heights which ranged from 17 to 19 m, 7.5 to 9 m, and 8 to 10 m, respectively. When the rain came, all canopies firstly intercepted by absorbing raindrops until saturated. So, the rest of raindrops would stemflow and throughfall to the lower canopies and the ground that covered with some grass as well as leaves and branches of the rubbers, Ironwoods, and bamboos that fallen and decayed. These layers helped prevent soil erosion caused by rainfall. The crown cover, that means the cover of canopies of all plants in the representative area was about 98% of the area. Also, the various roots of all plants had grown following crown cover, so they could hold topsoil to preserve soil erosion in plot.

Plot 2 Rubber-based sala fruit (Zalacca edulis Reinw.) and yangsain timber trees (dipterocarpus alatus Roxb.)

The techniques of plot management

Topography condition of this plot is upland area, and soil is sandy loam type. Rubber trees were planted on 10 rai area in 2005 by 7×3 m planting distance equalling to single row, 7 m inter-rows, and 3 m inter-tree in the same row. The rubber density is 76 trees per rai. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 3d/4 183/273 nil stimulation is used for the plot harvesting. In 2018, the rubber trees' girth at height 1.70 m from ground surface was 67.2 cm on average, and rubberwoods will harvest in 2045. Yangsain trees were planted in 2010 in the middle of rubber inter-row by 7×6 m planting distance equalling to single row, 7 m inter-row, and 6 m inter-tree in the same row. Yangsain tree density is 38 trees per rai. Its girth at height 1.30 m was 40.3 cm on average and the timbers will harvest in 2045. Furthermore, sala trees also were planted in the middle of rubber inter-row but it is only 5 rai in 2013 by double row (3×2 m) planting distance equalling to 3 m inter-row and 2 m inter-tree in the same row. The sala density is 228 trees per rai. There are 713 female and 427 male sala trees per 5 rai. They have been harvested since 2016 when they were 3-years old. Farmers always pollinate pollens of male sala on female sala trees' flower to formulate fruits. After that, the fruits will be harvested in 6 to 7 months. 10 female sala trees need 3 male sala trees to supporting pollen for formulating fruit every year. The sala trees always have been pruned after harvesting. This RAS plantation has not been applied any fertilizer for 10 years ago. Weeding has been practiced 2 times per year, only on tapping ways. Salas were not irrigated because the plot has enough moisture for all plants. Farmer reported that there are many birds and decomposed material to become organic fertilizers in this plot.

The economic margin

There are all 3 products in this plot rubber, yangsain trees, and sala fruits. In 2018, this plot was expended the total cost per rai equalled to 1,295 baht. Meanwhile, rubber product was 384 kg and sala product was 426 kg per rai that provided incomes 16,412 baht and 25,560 baht per rai, respectively. Yangsain and rubber trees will be cut down to provide wood income in 2045. Therefore, in 2018, the farmer got a total margin from this plot equalled to 40,677 baht per rai. Simulation of economic margin per rai for 6-year period from 2019 to 2024 with the related prices fixed in 2018 (Figure 3) show that farmer will get lower rubber income in sequence because the rubber product has been decreased by age. In 2024, the last year of the simulation, the rubber margin per rai will be 10,416 baht. The farmer will get more margins from sala fruits from year by year because the numbers of fruit have increased by age. The sala fruit margin will be 38,160 baht per rai higher than rubber margin about 72.70%. The total margin from this plot in 2024 equalled to 48,576 baht per rai higher than the total economic margin in 2018 for about 16.26%. Therefore, the farmer of plot 2 can overcome economic fluctuation even though rubber product has been decreased and rubber price is still low. Moreover, the plot still has yangsain and rubber trees whose economic values will be accumulated, and all trees can be greatly used for environmental services.

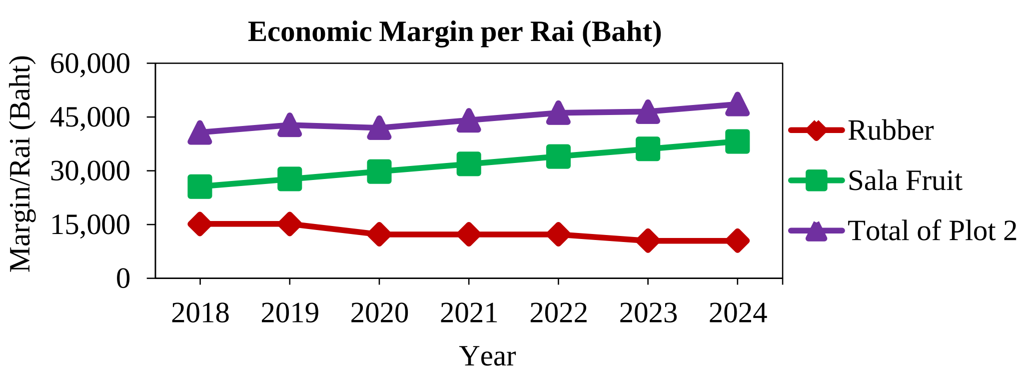
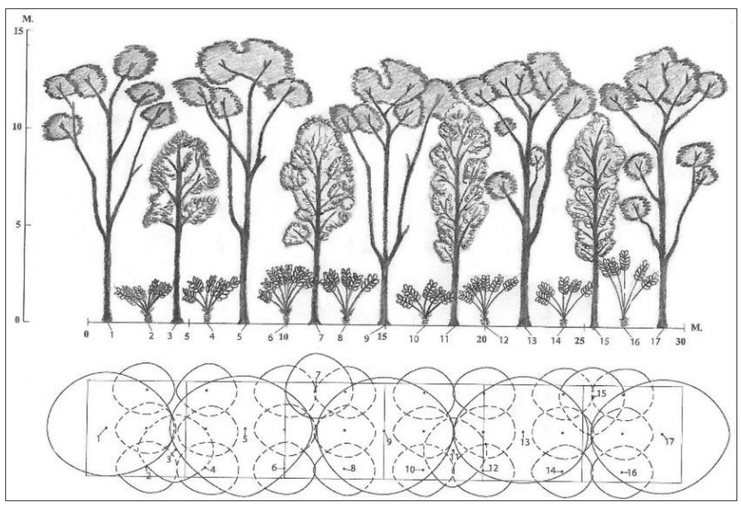


Figure 3. Economic margin of plot 2 from 2018 to 2024

The plant community structure and crown cover

The vertical plant community structure and crown cover in representative 5×30 m rectangle area of plot 2 was shown in Figure 4. The plant community structure was composed of rubber trees with upper canopies as well as yangsain and sala plants with lower canopies. The rubber trees, yangsain and sala plants had heights which ranged from 14 to 14.90 m, 10.10 to 12 m, and 2.50 to 3.10 m, respectively. When the rain came, all canopies firstly intercepted by absorbing raindrops until saturated. So, the rest of raindrops would stemflow and throughfall to the lower canopies and the ground that covered with some grass as well as leaves and branches of the rubbers, yangsain and sala plants that fallen and decayed. These layers helped to prevent soil erosion caused by rainfall. Meanwhile, the crown cover of the rubber trees, yangsain and sala plants in the representative area was about 98% of the area. So, the crown cover in plot 2 had a great potential to protect soil from direct rainfall in raining season and had ability to keep moisture in plot also due to multiple levels of vertical stratification and the crown cover percentages of the plant species. Also, various roots of all plants had grown following crown cover, so they could hold topsoil to preserve soil erosion in the plot.



Rubber trees	1, 5, 9, 13, 17
Yangsain trees	3, 7, 11, 15
Sala fruit plants	2, 4, 6, 8, 10, 12, 14, 16

Figure 4. The plant community structure and crown cover in the representative rectangular area (5×30 m) of plot 2

Plot 3 Rubber-based eaglewood tree (Aquilaria crassna Pierre.)

The techniques of plot management

Topography condition of this plot is upland area, and soil is sandy loam type. Rubber trees were planted on 16-rai area in 1997 by 8×3 m planting distance equaling to single row, 8 m inter-row, and 3m inter-tree in the same row. The rubber trees density is 66 trees per rai. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 3d/4 183/273 nil stimulation is used for the plot harvesting. Moreover, eaglewood trees were planted in the middle of rubber inter-row in 2004 by 8×3 m planting distance. So, the density is 66 trees per rai. Their branches have been pruned once a year. Eaglewood and rubber trees will be harvested timber at the same time in 2037. This RAS plantation has been applied, once a year in June, chemical fertilizer (30-30-68) alternating yearly with organic fertilizer about 50 kg per rai. Weeding has been practiced once a year before applying the fertilizers. Farmers asserted that this RAS plantation needs to practice weeding just once a year because weeds cannot grow well due to low sunlight access. The rubber trees provide more latex than rubber monocultures because in the plot there are more shade, moisture, and organic matter. In 2018, rubber girth at height 1.70 m was 78.8 cm and eaglewood girth at height 1.30 m was 65.7 cm on average from ground surface.

The economic margin

There are all 2 products in plot 3, i.e., rubber and eaglewood trees. In 2018, total cost of this plot was 7,153 baht per rai. Obviously, 83% of the total cost was expended on rubber tapping service. Meanwhile, rubber product was 395 kg per rai that provided income 16,082 baht per rai. Eaglewood and rubber trees will be cut down to provide wood income in 2037. Therefore, in 2018, the farmer got small margin from this plot about 8,929 baht per rai due to only one source of income and the high cost of this plot. Simulation of economic margin per rai for 6-year period from 2019 to 2024 with the related price fixed in 2018 (Figure 5) indicates that the farmer will get low and constant rubber margin every year because of low and stable products by old age of rubber trees. In 2024, rubber product will share the margin 8,929 baht per rai. Therefore, farmer of plot 3 will get single and stable income from rubber product for the 6-year simulation and will get additional income from eaglewood and rubber trees in the future beyond the simulation. And all trees can be greatly used for environmental services.

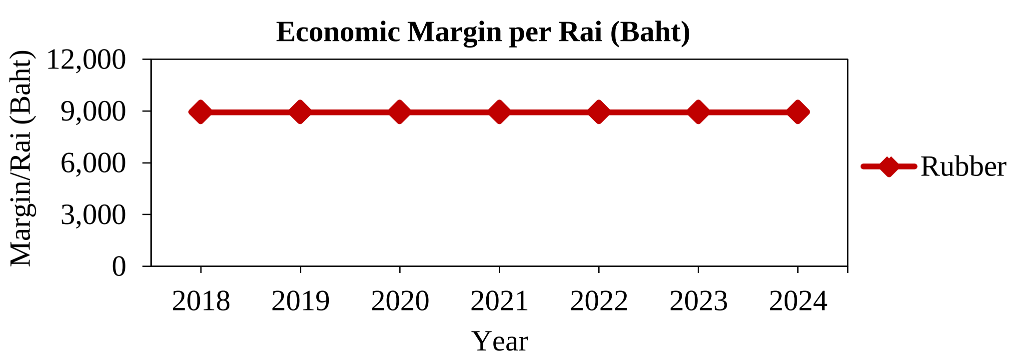
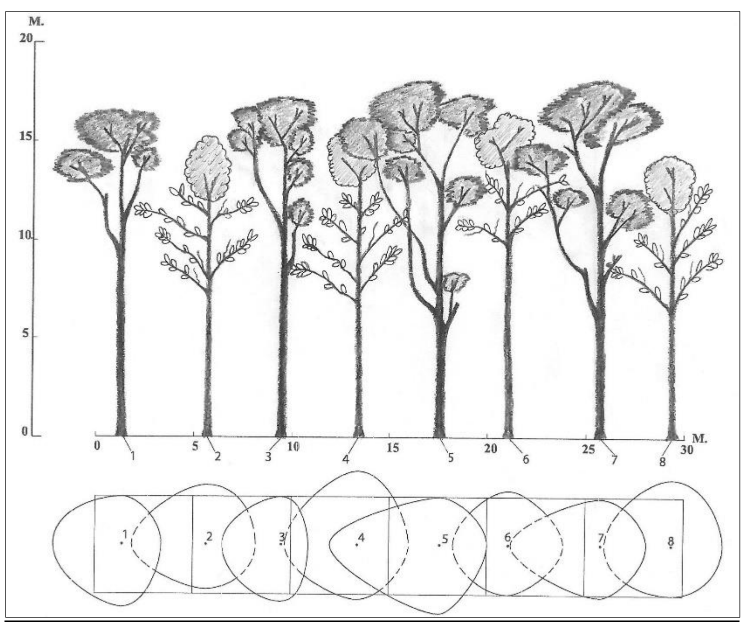


Figure 5. The economic margin of plot 3 from 2018 to 2024

The plant community structure and crown cover

The vertical plant community structure and crown cover in representative 5×30 m rectangle area of plot 3 was shown in Figure 6. The plant community structure was composed of rubber trees with upper canopies as well as eaglewood with lower canopies. The rubber trees, eaglewood had heights which ranged from 16.5 to 18 m and 15 to 16.5 m, respectively. When the rain came, all canopies firstly intercepted by absorbing raindrops until saturated. So, the rest of raindrops would stemflow and throughfall to the lower canopies and the ground that covered with some grass as well as leaves and branches of the rubbers and eaglewood that fallen and decayed. These layers helped to prevent soil erosion caused by rainfall. Meanwhile, the crown cover of the rubber trees and eaglewood in the representative area was about 93% of area. So, the crown cover in plot 3 had a great potential to protect soil from direct rainfall in raining season and had ability to keep moisture in plot also due to multiple levels of vertical stratification and the crown cover percentages of the plant species. Also, various roots of all plants had grown following crown cover, so they could hold topsoil to preserve soil erosion in the plot.



Rubber trees	1, 3, 5, 7
Eaglewood trees	2, 4, 6, 8

Figure 6. The plant community structure and crown cover in the representative rectangular area (5×30 m) of plot 3

Plot 4 Rubber-based champadak (Artocarpus integer Merr.), phakleang (Gnetum gnemom var.)

The techniques of plot management

Topography condition of this plot is upland area, and soil is sandy loam type. Firstly, rubber trees were planted on 8-rai area in 1997 by 10×2.5 m planting distance equalling to single row, 10 m inter-row, and 2.5 m inter-tree in the same row. The rubber trees density is 64 trees per rai. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 2d/3 120/182 nil stimulation is used for the plot harvesting. Rubber wood will harvest in 2037. Secondly, champadak fruit trees (20 trees per rai), longkong fruit trees (2 trees per rai), durian fruit trees (2 trees per rai), and mangosteen fruit trees (2 trees per rai) have been planted at the same time and area with the rubber trees by 10×6 m planting distance equalling to single row, 10 m inter-row, and 6m inter-tree in the same row. So, their density is 26 trees per rai. Longkong, durian and mangosteen have been planted for consumption in the household only, they are not for economic income. Thirdly, phakleang, a vegetable plant, has been planted in the middle of rubber inter-row in 2017 by 5×2.5 m planting distance. So, the density is 128 trees per rai. The farmer has harvested phakleang products since they were 6 months old amount 40 weeks per year. This RAS plantation has been practiced weeding, 2 times per year. Farmers asserted that this RAS plantation did not need to apply chemical fertilizer because the fallen leaves of all plants decompose into organic fertilizer. All plants in this plot help keep moisture especially during dry season for first growing rubber leaves after fallen leaves period. This RAS practice is better way because there are microorganisms, biodiversity in plot and many birds also; and it helps reduce fallen leaves period of rubber trees. In 2018, rubber girth at height 1.70 m from ground surface was 79.4 cm on average and champadak girth at height 1.30 m from ground surface was 68.6 cm on average.

The economic margin

There are 3 main products which are economic income of plot 4: rubber products, champadak fruits, and phakleang leaves as vegetable. In 2018, total cost per rai of this plot equalled to 1,190 baht. The rubber product was 243 kg, champadak product was 1,190 kg, and phakleang product was 480 kg per rai that provided income 10,386, 23,800, and 12,000 baht per rai, respectively. Rubberwood will provide income in 2037. As a result, the farmer got all margin from this plot equalled to 44,996 baht per rai in 2018. Simulation of economic margin per rai for 6-year period from 2019 to 2024 with related prices fixed in 2018 (Figure 7) showed that, the farmer will get low and constant rubber margin every year because of low and stable products by old age of rubber trees. Meanwhile, the products of champadak and phakleang will increase every year, in the last year of the simulation (2024), the rubber products, champadak fruits, and Phakleang leaves will share the margin 9,196, 36,800, and 16,500 baht per rai, respectively. The total margin from this plot in 2024 equalled to 62,496 baht per rai higher than total margin in 2018 about 28%. Therefore, plot 4 owner can overcome the low rubber products and price by introducing the intercrops in the plot. Moreover, the plot still has wood products of rubber trees and champadak trees whose economic values will be accumulated by age, and all trees can be greatly used for environmental services.

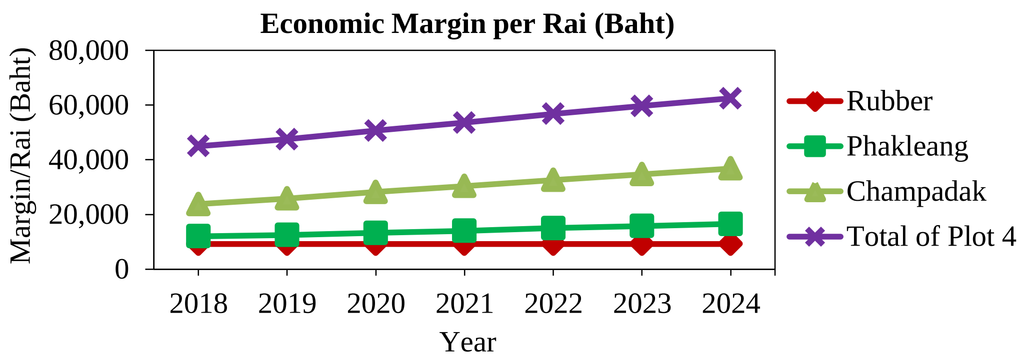
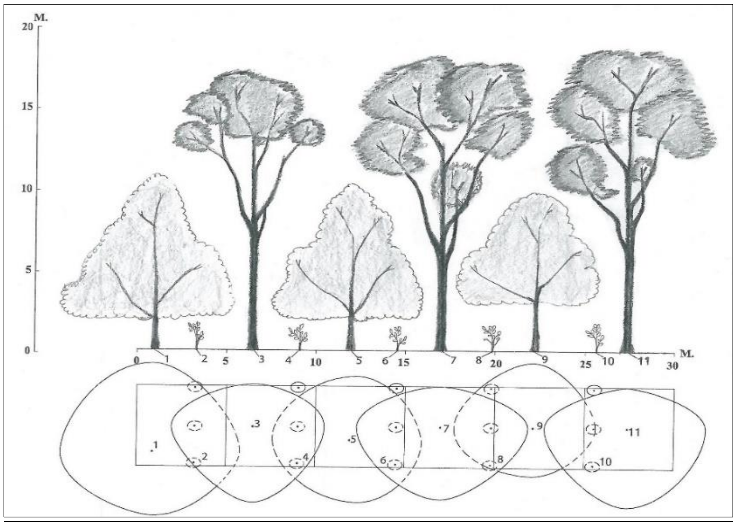


Figure 7. The economic margin of plot 4 from 2018 to 2024

The plant community structure and crown cover

The vertical plant community structure and crown cover in representative 5×30 m rectangle area of plot 4 was shown in Figure 8. The plant community structure was composed of rubber trees with upper canopies as well as champadak trees, and phakleang with lower canopies, respectively. The rubber trees, champadak trees and phakleang crops had heights which ranged from 17.5 to 18.5 m, 9.5 to 11 m, and 1.50 to 1.70 m, respectively. When the rain came, all canopies firstly intercepted by absorbing raindrops until saturated. So, the rest of raindrops would stemflow and throughfall to the lower canopies and the ground that covered with some grass as well as leaves and branches of the rubbers, champadak trees and phakleang crops that fallen and decayed. These layers helped to prevent soil erosion caused by rainfall. The crown cover of the rubber trees, champadak trees and phakleang plants in the representative area was about 98% of the area. So, the crown cover in plot 4 had a great potential to protect soil from direct rainfall in raining season and had ability to keep moisture in plot due to multiple levels of vertical stratification and crown cover percentages of the plant species. Also, various roots of all plants had grown following crown cover, so they could hold topsoil to preserve soil erosion in plot.



Rubber trees	3, 7, 11
Champadak fruit trees	1, 5, 9
Phakleang vegetable plants	2, 4, 6, 8, 10

Figure 8. The plant community structure and crown cover in the representative rectangular area (5×30 m) of plot 4

Plot 5 Rubber-based coffees fruit (Coffea Arabica)

The techniques of plot management

Topography condition of plot 5 is upland area, and soil is sandy loam type. Rubber trees were planted on 5-rai area in 2007 by 7×3 m planting distance equalling to single row, 7 m inter-row, and 3 m inter-tree in the same row. The rubber density is 76 trees per rai. The farmer started tapping when rubber trees were 7 years old. Tapping system as S/3 3d/4 183/273 nil stimulation is used for the plot harvesting. Rubberwood will be harvested in 2047. Besides, in 2013, coffee fruit trees were planted on only 3 rai of the 5-rai plot in the middle of rubber inter-row by (5+2 m)×2.5 m planting distance equalling to double rows, 2 m and 5 m inter-rows, and 2.5 m inter-trees in the same row. So, the coffee tree density is 182 trees per rai. Coffee fruits have been harvested since they were 4 years old. The farmers always harvest them once a year in October. This RAS plantation has been applied organic fertilizer about 25 kg per rai per time with 2 times per year in May and October. Weeding has been practiced 2 times per year before applying the fertilizer. The Farmers asserted that in this RAS plantation, weeds cannot grow well, and the rubber trees provide more latex than rubber monoculture plots also. Because there are more shade, moisture, and organic matter in plot. In 2018, rubber girth at height 1.70 m from ground surface was 62.9 cm on average.

The economic margin

There are all 2 products in this plot: rubber and coffee. In 2018, the total cost per rai in this plot was 1,645 baht. The rubber product was 371 kg and coffee fruit product was 100 kg per rai that provided income 15,857 and 4,300 baht per rai, respectively. Rubber wood will provide income in 2047. Therefore, the farmer got total margins from this plot about 18,512 baht per rai. Simulation in the future for 6-year period from 2019 to 2024 with related prices fixed in 2018 (Figure 9) indicated that rubber income will decrease in sequence because the rubber products will decrease by age. Coffee fruit income will increase from year by year due to the yield increase by age of coffee trees. In the last year of the simulation (2024), the rubber and coffee products will share the margin about 9,359 and 8,885 baht per rai, respectively. The total margin from this plot in 2024 equalled to 18,244 baht per rai lower than the total margin in 2018 about 1.44%. Therefore, the coffee fruits of plot 5 can compensate for the decreasing product and low price of rubber due to getting additional income from coffee. Moreover, the plot still has rubberwood whose economic values will be accumulated every year, and all plants can be greatly used for environmental services.

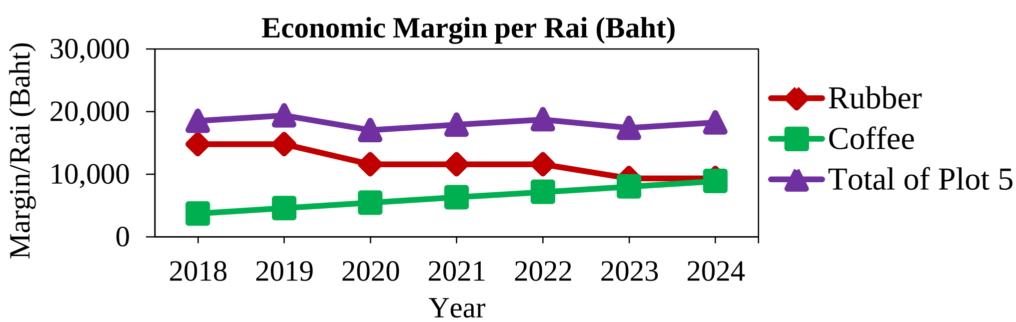
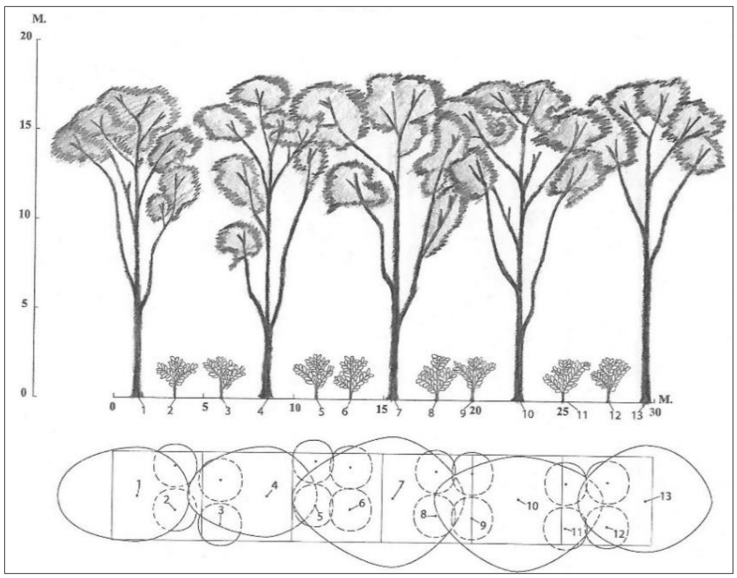


Figure 9. The economic margin of plot 5 from 2018 to 2024

The plant community structure and crown cover

The vertical plant community structure and crown cover in representative 5×30 m rectangle area of plot 5 was shown in Figure 10. The plant community structure was composed of rubber trees with upper canopies as well as coffee trees with lower canopies. The rubber trees, coffee trees had heights which ranged from 18 to 18.5 m and 2.20 to 2.5 m, respectively. When the rain came, all canopies firstly intercepted by absorbing raindrops until saturated. So, the rest of raindrops would stemflow and throughfall to the lower canopies and the ground that covered with some grass as well as leaves and branches of the rubbers and coffee trees that fallen and decayed. These layers helped to prevent soil erosion caused by rainfall. Meanwhile, the crown cover was about 95% of the area. So, the crown cover in plot 5 had a great potential to protect soil from directly rainfalls in raining season and had ability to keep moisture in plot due to multiple levels of vertical stratification and crown cover percentages of the plant species. Also, various roots of all plants had the crown following crown cover, so they could hold topsoil to preserve soil erosion in the plot.



Rubber trees	1, 4, 7, 10, 13
Coffee fruit plants	2, 3, 5, 6, 8, 9, 11, 12

Figure 10. The plant community structure and crown cover in representative rectangular area (5×30 m) of plot 5

Discussion

In terms of plot management, all 5 RAS plots in this study are planted rubber trees by 7×3 m, 8×3 m and 10×2.5 m planting distance. RAS plot 3 have been applied with chemical and organic fertilizers. RAS plot 1 and 5 have been applied only organic fertilizer, but RAS plot 2 and 4 have not been applied fertilizer because there are much humidity and plant nutrient cycling in the plots. Chen *el al*. (2019) revealed that the RAS had significantly improved the soil physical and hydrological properties, and soil nutrients had been improved by intercropping. All RAS owners in this study used mechanic method for weeding, it is good strategy for reducing chemical method to restore natural environment.

In this study, economic margins were divided into 3 levels of ability to overcome low rubber price: high, medium, and low level. Figure 11 show that plot 1, 2 and 4 were high level, plot 5 was medium level, and plot 3 was low level of ability to overcome low rubber price. However, eaglewood trees in plot 3 will provide a great margin to compensate for the previous low margins in the future but that beyond the simulation period. Also, coffee trees in plot 5 will increase products from year by year after the simulation period. RAS practices are an alternative to improve household livelihood of RAS farmers though rubber price is decreased. Somboonsuke *et al*. (2019) exposed that in 10-year economic model (2017-2026) of different farmers practice of two different systems got the different total income. Farmers practice rubber mono-farming system had the lowest income and those practice RAS get high income, so livelihood of RAS farmers is success. Jongrungrot (2016) had shown that RAS is the most resistant to uncertainties and risks of economic fluctuation because various incomes were derived from various products of other plants and/or animals during long none-tapping period of rubber trees as well as increasing more income during rubber trees harvesting also (Stroesser *et al*., 2018).

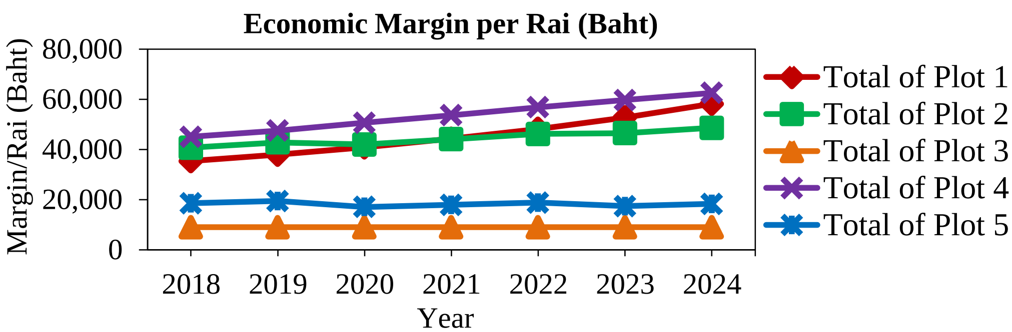


Figure 11. The economic margin of 5 plots from 2018 to 2024

On another hand, the plant community structure was composed of rubber trees with upper canopies as well as intercropping plants with lower canopies. When the rain came, all canopies would reduce the strength of raindrops. Then, the ground that covered with some grass, as well as leaves and branches of the rubber and intercropping trees that fallen and decayed could receive the rest of raindrops. These layers helped to prevent soil erosion caused by reducing strength of rainfall. The soil cover (crown cover) by the canopy density was more than 70% in plot could reduce soil erosion (Ruangpanit, 2014). In this study, the crown cover of rubber trees and intercrops in representative areas of all 5 plots ranged from 93 to 98% of the areas. Therefore, they had a great potential to protect soil from direct rainfall in raining season, and had ability to keep moisture in plot due to multiple levels of vertical stratification and crown cover percentages of the plant species. Kittitormkool (2019) presented that the average cover of diverse plant species in RAS over 80% could enhance its natural capital, including soil, biodiversity, water, ecosystem, and natural resources.

All plants need sunlight for photosynthesis, and they need more or less sunlight depended on species of plants. Thus, the plants which use not much sunlight for photosynthesis should be associated with rubber plantation as RAS. Some rubber clones which grow straight up such as RRIM 728, RRIM805, RRIM901, PB217, PB260, PB254, RRIC 100, BPM1, *etc*. are good for excellent RAS practice (Wibawa *et al*., 2007; Board, M. R., 2009). As well, planting distance design should be flexible with species of intercrops. For instance, farmers who practice rubber-based timber trees and rubber-based fruit trees suggested that rubber planting distance in RAS should expand line spacing of rubber inter-row such as 8×3 m, 8×2.5 m, 10×3 m, 10×2.5 m, *etc*. Zeng (2012) resulted that the rubber trees' girth in the (20+4 m) ×2 m planting distance at the first year was slightly bigger than the rubber trees' girth in the 7×3 m planting distance. The (20+4 m) ×2 m planting distance had a larger full-sun area of land with high light penetration providing suitable conditions for the long-term intercrops. Additionally, livestock can be supplementary economic activity on RAS farms. According to the result of this study, raising bee in RAS plot provides good additional income to farmers with low costs, and the bee is the good insect as it also plays a role of a pollinator. Consequently, RAS practice should be associated with livestock as the third product on farms to increase household income and food security.

Acknowledgements

The authors would like to offer particular thanks to Her Royal Highness Princess Maha Chakri Sirindhorn scholarship and Research Fund of Faculty of Natural Resources, Prince of Songkla University that supported this study.

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(Received: 23 January 2020, accepted: 10 December 2020)